

## **Methodological aspects of a mathematical programming model to evaluate soil tillage technologies in a risky environment**

### **Abstract**

With this work we develop a methodology able to ensure the economic evaluation of soil tillage technologies, in a risky environment, and to capture the influence of farmer behaviour on his technological choice.

The model has short term activities, that change with the type of year and long term activities, in which the sets of traction investment activities are included. Although these activities do not change with the type of year, they lead to different availability of resources each type of year, since the same tractor has different available days to work in the field in different weather conditions.

We prove that the model is sensible to the greater income variability resulting from the use of alternative technologies and to the balance between income and risk, accounting to the probability of occurrence of each state of nature and giving an investment solution that considers each year the best production plan.

**Keywords:** Decision Analysis; Risk Management; Linear Programming; OR in agriculture;

### **1. Introduction**

The aim of this work is to develop a methodology that is able to ensure the economic evaluation of soil tillage technologies, in a risky environment, and to capture the influence of farmer behaviour on his technological choice.

Alternative soil tillage technologies, namely direct seeding and reduced mobilization, can play an important role on the maintenance of farms competitiveness (Martins, 1994). In a risky environment the methodology used to the economic evaluation of alternative soil tillage technologies should incorporate in the analysis the greater inter-annual production variability of these technologies, when compared with traditional technology, and the inter-annual variability of the available days to perform the cultural operations needed to establish the cereals, since the available days are an important issue on the economic analysis of technologies and different types of years lead to different availability of days.

The farmer behaviour is another key issue. The income risk that tillage technologies have is due to production risk and to resources risk, given by the inter-annual variability on productions and available days. Farmers' risk aversion may condition their technological option.

In this work, resources and productions variability's are incorporated in a linear programming model. Carvalho (1994) refers that a huge number of studies at farm level, focused on farm planning in a risky environment, have been developed with the use of mathematical programming models, linear or not. Risk modelling techniques are built to produce a plan which, according to the producer preferences, maximizes his total satisfaction.

With mathematical programming it is possible to compare various technological options and consider the natural and economical factors influencing the technology use (Spharín & Seligman, 1983). The possibility of modelling the production system allows a set of efficient combinations of resources and products definition and the best selection (Boussard, 1971). Beside that, this method allows the system's interactions consideration (Knipscheer *et al.*, 1983).

## **2. The risk introduction on the technological economic evaluation problem**

At farm level the income risk may affect the farm economical result expected value and the farmer options in what concerns the utilization of alternative farm tillage technologies.

The risk farmer faces in his farm may be due to environmental, political and institutional causes, depending on the use of production factors. The income risk comes from production risk, prices risk or resources risk that these causes imply simultaneously or not (Hardaker, *et al.*, 1997, pág. 6).

Agricultural production is typically a risky activity and it is important to consider risk when planning a farm business. Costs and profits are influenced, during the production process, by the causes referred before, not controlled by farmer, and this affects the decisions at farm level – it is not expectable that farmers are pure profit maximizers (Carvalho, 1994).

Risk treatment in agriculture has been widely treated by several authors (Hazell & Norton, 1986; Rae, 1994, Hardaker, *et al.*, 1997). Mathematical programming formulations use risk considering the stochastic parameters distribution is known. Once we know a probability distribution of the parameters the problem will be to represent this distribution inside the model structure (Carvalho, 1994).

The Expected Value/Variance model (Freund, 1956) brings the risk to the objective function, being used to generate the set of farm plans on the Expected Value/Variance frontier. This model can be linearly approximated using the MOTAD (Hazell, 1971), which doesn't use the variance but the total absolute deviation, a linear estimator of variance, allowing the calculus of Risk/Income frontier by using linear programming.

The MOTAD model generates a Risk/Income frontier close to the Expected Value/Variance frontier but with slightly lower probability of containing the farmer's expected utility maximizing solution (Hardaker *et al.*, 1997).

The decision, according to these models, only depends on income average and variance, and the results assume a normal distribution.

Cocks (1968) suggested discrete stochastic programming model can give solutions to decision problems in which some of the technical coefficients and/or resources used can be well explained by a discrete probabilities distribution and Rae (1971) showed these models potential to solve stochastic decision problems.

### **3. Risk evaluation**

Agricultural administration often requires that farmer take decisions without certain knowledge of these decisions' implications. This way, many farms administration problems can be expressed by the decision theory since they involve the specification of possible actions, states of nature, states of nature probability of occurrence and an utility function to maximize (Rae, 1971).

Soil tillage technology choice represents a typical decision problem: the choice of optimal activities combination which differs among them in what concerns risk and expected income (Feder, 1980). So, the decision analysis in this context should be made using a method that allows the consideration of decision maker's attitude to risk.

Decision theory is based on the subjective expected utility theory, which axioms have been specified by Bernoulli and, later, Von Neuman & Morgenstern.

A rational choice considering risk can be defined as a choice consistent with the decision maker's beliefs about the chances of occurrence of alternative uncertain consequences and with his relative preferences for those consequences (Hardaker, *et al.*, 1997, p. 29). The subjective expected utility theory is based exactly on these principles. The probabilities of occurrence of chance consequences reflect and quantify the decision maker expectations, while preferences translate his attitude to the consequences of the decision, i.e., to risk.

A risk averter decision maker will prefer less risky decision, which probability of occurrence of chance consequences that means significant losses is low, although the expected income is lower then the obtained with a riskier decision while a risk preferrer will prefer a risky decision even though the occurrence probability of chance consequences giving significant returns is not high. Only a decision maker indifferent to risk will base his decision exclusively on expected income (Hardaker, *et al.*, 1997, p. 87).

The problem of choice rationality considering risk in order to use the subjective expected utility theory is linked with the possibility of risk elements incorporation, related with uncertainty on resources availability and on the adjustment of input-output coefficients depending on the state of

nature. Considering this, the discrete stochastic programming model associated to a MOTAD structure suggested by Marques (1988) is the most suitable for the evaluation.

#### 4. The farmer decision

Decision making is hardly neutral to risk and neglecting risk aversion in agricultural models can lead to an important overestimation of production levels and also influence farmer behaviour through proposed new technologies.

Specifically on problem decision's context of soil conservation practices utilization, such as alternative soil tillage technologies, Nowak & Wagner, mentioned by Kramer *et al.* (1983) state that risk aversion attitudes may affect farmer's decision and that the investigation on the relation between risk and farmer's behaviour would be very useful to the design and implementation of a soil conservation policy.

As we already said, the subjective expected utility hypothesis demonstrates how we can integrate the two components of utility (preferences) and probabilities (individual expectations) to rationalize a risky choice (Hardaker *et al.*, 1997, p. 87).

Many methods have been used to elicit decision makers' information so their preferences can be established and translated into a utility function (Hardaker, *et al.*, 1997, p. 88).

Nevertheless, Thorton (1985) and Romero *et al.* (1988) underlined the difficulties of establishing a reliable representation of iso-utility functions family since it depends on some rigid assumptions about farmer behaviour. Ballesterro & Romero (1991) stated that in real life is almost impossible to obtain a reliable mathematical representation of a decision maker actual utility function.

They proposed a combination of Compromise Programming (CP) with the risk modelling models (such as MOTAD), leading to the Compromise Programming with Risk (CPR). This method avoids the problem of determining the farmer's utility function, limiting the extreme points of the efficient set, where occurs the tangency with the iso-utility curves.

The basic idea on Compromise Programming is to identify the ideal solution as the point where each studied objective has his optimal value. When there is a conflict between the objectives, the ideal point is an impossible solution and it is used only as a reference. Compromise Programming assumes that any decision maker looks for a solution as close as possible to the ideal (*Zeleny's axiom of choice*).

The coordinates of the ideal point are given by the optimal values of farmer's various objectives. To measure the more or less proximity to the ideal point of any given efficient point, Compromise Programming uses distance functions.

Geometrically, in a Cartesian plan, the Euclidian distance, or the shorter distance between two points  $A = (x_1^a, x_2^a)$  e  $B = (x_1^b, x_2^b)$  is given by:

$$d = \left( x_1^a - x_1^b \right)^2 + \left( x_2^a - x_2^b \right)^2$$

In a n-dimensional space, the Euclidian distance between point  $A = (x_1^a, x_2^a, \dots, x_n^a)$  and  $B = (x_1^b, x_2^b, \dots, x_n^b)$ , is given by (Romero, 1993):

$$d = \sqrt{\sum_j^n \left( x_j^a - x_j^b \right)^2}$$

Although this kind of distance is the best known and the more used in geometrically defined problems, it is not the only one nor even the best suited for all problems, because the geometric sense of distance isn't always suitable for the proposed objectives.

In Compromise Programming, the distance concept is used as a measure of human preferences rather in the geometric sense of the term. Mathematically the distance concept can be generalized, introducing the metrics  $L_p$ , which lead to the following generalization of Euclidian distances (Romero & Rehman, 1985):

$$L_p(K) = \left[ \sum_{j=1}^n \left| x_j^1 - x_j^2 \right|^p \right]^{1/p}$$

where K is the number of objectives and p weights the magnitude of the difference between the objective j and the ideal point.

Yu (1973), referred by Romero *et al.* (1988), has proved that metric  $L_1$  (for  $p=1$ , the longer distance in a geometric sense) defines one of compromise set (tangency segment between iso-utility curves and efficient frontier) boundaries while the other corresponds to metric  $L_\infty$  (for  $p=\infty$ , the Chebysev's distance). Ballestero & Romero (1991) formulated a theorem which proves, given the axioms which define utility theory, that the optimal solution occurs inside the compromise set.

The first step to use this method to any problem is, of course, to obtain the ideal vector, which contains the ideal values for each objective, and the anti-ideal vector, which contains the worst values for each objective.

To determine the solutions we have then to define the proximity degree  $d_j$ , between the j objective and is ideal, given by:

$$d_j = |f_j^* - f_j(x)|$$

where  $f_j^*$  represents the ideal value to the  $j$  objective (Romero, 1993).

Once we have defined this proximity degree, the next step is to aggregate the proximity degrees for all the objectives of the problem. Since these objectives can be measured in different unities or have very different absolute values, we have to homogenise them, so their sum is not senseless. To do so, we divide the proximity degree  $d_j$  by the sum, in absolute terms, between the ideal value of  $j$  objective ( $f_j^*$ ) and the anti-ideal value of the same objective ( $f_{*j}$ ) (Romero, 1993).

The normalized proximity degree,  $d_j$ , between the  $j$  objective and its ideal is given by (Romero, 1993):

$$d_j = \frac{|f_j^* - f_j(x)|}{|f_j^* - f_{*j}|}$$

This means that the normalized proximity degree is always a value between 0 and 1: when an objective reaches its ideal value its proximity degree is 0 and when the objective reaches its anti-ideal value its proximity degree is 1.

If we represent by  $W_j$  the preferences the decision maker associates to the difference between what he achieves to the  $j$  objective and its ideal, compromise programming becomes the following optimization problem (Romero, 1993):

$$\text{Min } L_p = \sum_{j=1}^n \left[ W_j^p \left| \frac{f_j^* - f_j(x)}{f_j^* - f_{*j}} \right|^p \right]^{1/p}$$

We can calculate metrics  $L_1$  and  $L_\infty$  to the studied problem and limit the compromise set, inside which we have the optimal solution, which maximizes the farmer's expected utility.

## 5. Methodological approach

Methodology choice considered that we needed to make an economical evaluation of soil mobilization technologies considering how risk and farmer's risk behaviour determine their technological choice.

Agricultural enterprises models, representing a set full of interactions at products and resources level allows the analysis of farmer's answer to its decision problem, admitting the decision is rational and conditioned by the scarce resources the farmer has.

The used method should be able to simulate the farmers decision that knowing the time needed for seeding operation, depending on technology and the investment cost each technology implies, has an income risk coming mainly from his production and resources risks:

- From cereal production, which is different for each technology although the average production is the same.
- From available days to seed on each technology, each type of year, considering the technology influence on the soil.

The model must consider these aspects and account their influence on economical evaluation of Technologies. This evaluation is influenced by stochastic parameters, which values are only known after the investment but which probability of occurrence distribution is known.

Model solution optimizes the farmer's decision, indicating the best investment alternative, considering the probability of occurrence of different type of years and the production plan that best fits the farm, each type of year.

Assuming the farmer's objective is the maximization of the expected income, which means it is neutral to risk, its decision problem can be stated as follows:

$$MaxZ = \sum_s P_s \left[ \left( \sum_j (r_j f_{js}(k_{js}) - c_j k_{js}) x_{js} \right) - (c_t x_t) \right]$$

s.t.

$$\sum_j x_{js} \leq S$$

$$\sum_j x_{js} - x_t \leq 0$$

$$x_{js} \geq 0; x_t \geq 0; k_{js} \geq 0;$$

where Z is the objective function, which represents the long term economical result,  $P_s$  is each state's of nature  $s$  probability of occurrence;  $r_j$  is the profit of  $j$  product;  $f_{js}$  is the continuous production function by  $j$  production unit on state  $s$ ;  $k_{js}$  is the vector representing the amount of production factors used on short term activity  $j$  during state of nature  $s$  by production unit;  $c_j$  is the unit cost of

production factors used on short term activity  $j$ ;  $c_t$  is the unit cost of long term activity  $t$ ;  $S$  is the amount of resources available in the enterprise;  $x_{js}$  represents the units of  $j$  activity in state of nature  $s$ ; and  $x_t$  is the amount of long term activities  $t$ .

We've introduced farmer's behaviour using Compromise Programming, which means we've introduced in this model the distance functions  $L_1$  and  $L_\infty$ . To calculate  $L_1$ , the model structure is modified this way:

$$MinL_1 = W_1 \frac{Z^* - Z}{Z^* - Z_*} + W_2 \frac{D^* - D}{D^* - D_*}$$

s.t.

$$Z = \sum_s P_s \left[ \left( \sum_j (r_j f_{js}(k_{js}) - c_j k_{js}) x_{js} \right) - (c_t x_t) \right]$$

$$\sum_j x_{js} \leq S$$

$$\sum_j x_{js} \leq 0$$

$$\left[ \left( \sum_j (r_j f_{js}(k_{js}) - c_j k_{js}) x_{js} \right) - (c_t x_t) \right] - Z + D_s \geq 0$$

$$\sum_s D_s = D$$

$$x_{js} \geq 0; x_t \geq 0; k_{js} \geq 0;$$

where all the variables have mean the same as before,  $D_s$  is the deviation of income  $Z_s$  in each state of nature  $s$ , from average  $Z$  and  $D$  is the total absolute deviation.  $Z^*$ ,  $D^*$ ,  $Z_*$  and  $D_*$ , represent respectively, the best and worse values to long term economic result and total absolute deviation and  $W_1$  and  $W_2$  represent the weight of each objective – the maximum long term economic result and minimum total absolute deviation – on the objective function.

To calculate  $L_\infty$  the model will be modified as follows:

$$MinL_\infty = d$$

s.t.

$$Z = \sum_s P_s \left[ \left( \sum_j (r_j f_{js}(k_{js}) - c_j k_{js}) x_{js} \right) - (c_t x_t) \right]$$

$$W_1 \frac{Z^* - Z}{Z^* - Z_*} \leq d$$



$$W_2 \frac{D^* - D}{D^* - D_*} \leq d$$

$$\sum_j x_{js} \leq S$$

$$x_{js} \geq 0; x_t \geq 0; k_{js} \geq 0;$$

where variables mean the same as before and d is the maximum deviation among all individual deviations.

## 6. The mathematical programming economic model formulation

The stochastic discrete programming method suggested by Cock, in 1968, which potential to solve stochastic decision problems Rae demonstrate in 1971, is well suited to identify the farmer's long term investment decision, considering the stochastic parameters already identified and their probability of occurrence distribution. Modelling different states of nature we represent types of years in which the conjunction of temperature and precipitation effects on some critical periods determine the final production and also consider the farmer's investment decision. This decision supposes an optimal resources distribution each year, i.e., the adjustment that ideally the farmer should make annually to his farm plan.

To simulate the farmer's decision we've built a discrete stochastic programming model associated to a MOTAD structure (Marques, 1988), maximizing the income expected value, subjected to long term restrictions only in what concerns available land. We've economically evaluated soil tillage technologies and income variability on a neutral situation in what concerns risk. With this model we could also determine the ideal and anti-ideal vectors.

After this, we used Compromise Programming with Risk to calculate the portion of the efficient set where the tangency point between this set and iso-utility curves will occur.

The mathematical programming economical model applied to a characteristic enterprise of *Beja Clay Zone*, in the South of Portugal, supposes the farmer can choose among the studied three soil tillage technologies – traditional technology, reduced mobilization and direct seeding – taking into account the soil and climatic factors (temperature, precipitation and soil type) that influence the cereals conditions and growing periods, then influencing final production; the technical and institutional factors, by including in the model activities and restrictions that model the resources use and consider the prices and markets and the socio-structural policies effects in agriculture.

Variables definition and the parameters used in the model as well as its mathematical formulation are in annex 1.

## 7. Model results

In the next table (table 1) we present the economic model results in what concerns each state of nature annual result, costs and profits for base situation (with only traditional mobilization) and for technological alternatives situation and also the expected values. This annual result should clearly show the farmer's decision influenced by the different states of nature's probability of occurrence, and also which is the best exploitation plan for each type of year.

The costs and profits structure is divided as follows:

- Traction costs are in separate lines and divided in fixed costs, variable costs and extra hours' costs.
- Work costs are also in separated lines, divided in permanent and eventual work. In permanent work we included the sheppard work. Although this is not an integer variable, which means we are talking of sheppard hours, we admit these hours are needed all over the year and so this work should be seen as permanent.
- Profits with products selling and subsidies and costs with other production factors are presented together for all the crops.
- For sheep production we present only the annual result (profits + subsidies – costs with production factors) and, in a separate line, costs with feeding, since animal feeding needs are calculated by the model considering animal needs, feed at disposal from crop activities, selling price for crop products and buying price for sheep granulate.

This way, profits are divided as sheep result, crops selling, straw selling and subsidies to crops and costs are divided as bought production factors for crops, granulate costs, fixed costs, variable costs and extra hours costs with traction, eventual work costs and permanent work costs..

**Table 1** – Current results for the studied enterprise and negative deviation, each type of year, expected income and total absolute deviation for base and technological alternatives' situations.

Unit: Euros

<i>State of nature</i>	1	2	3	4	5	6	Average
<i>Percentage of occurrence</i>	11%	14,5%	14,5%	22%	19%	19%	
<b>Base situation</b>							
<b><i>Annual Result</i></b>	<i>101.091</i>	<i>50.344</i>	<i>29.070</i>	<i>11.018</i>	<i>5.352</i>	<i>9.412</i>	<i>27.950</i>
Sheep result	17.363	17.363	17.363	17.363	17.363	17.363	17.363
Crops selling	126.336	93.240	77.957	62.440	61.916	61.651	75.935
Straw selling	11.482	3.566	2.359	643	424	4.010	3.106
Crops' subsidies	120.385	112.773	107.785	87.160	98.877	102.633	102.685
<b><i>Total Profits</i></b>	<i>275.566</i>	<i>226.943</i>	<i>205.470</i>	<i>167.601</i>	<i>178.580</i>	<i>185.653</i>	<i>199.089</i>
Production factors for crops	64.290	64.285	64.290	51.690	60.389	64.285	60.775
Granulate costs	1.716	4.609	4.205	2.923	4.464	4.205	3.757

Fixed costs with traction	16.765	16.765	16.765	16.765	16.765	16.765	16.765
Variable costs with traction	64.210	64.180	64.210	51.925	60.749	64.180	60.840
Extra hours costs with traction	0	0	0	6.494	4.270	0	2.240
Eventual work costs	1.766	1.033	1.202	1.057	863	1.082	1.120
Permanent work costs	25.728	25.728	25.728	25.728	25.728	25.728	25.728
<b>Total costs</b>	<b>174.475</b>	<b>176.594</b>	<b>176.400</b>	<b>156.583</b>	<b>173.228</b>	<b>176.240</b>	<b>171.224</b>
<b>Negative deviation each s.n.</b>	-	-	-	16.849	22.521	18.456	
<b>Expected income</b>	27.950						
<b>Total absolut deviation</b>	57.965						
<b>Tecnhological alternative</b>							
<b>Annual Result</b>	79.980	160.930	50.940	21.855	18.345	9.805	49.675
Sheep result	16.101	16.101	16.101	16.101	16.101	16.101	16.101
Crops selling	101.520	151.340	79.638	57.881	52.962	48.797	76.727
Straw selling	4.050	10.126	3.876	793	728	4.554	3.654
Crops' subsidies	115.058	122.046	108.199	89.105	86.107	97.989	100.623
<b>Total Profits</b>	<b>236.729</b>	<b>299.613</b>	<b>207.809</b>	<b>163.875</b>	<b>155.899</b>	<b>167.436</b>	<b>197.103</b>
Production factors for crops	64.624	55.870	65.512	56.648	55.691	65.752	60.246
Granulate costs	5.427	1.521	5.427	5.597	5.597	4.998	4.849
Fixed costs with traction	18.241	18.241	18.241	18.241	18.241	18.241	18.241
Variable costs with traction	42.398	39.071	42.378	35.624	33.958	42.767	38.889
Extra hours costs with traction	7.073	4.240	6.210	7.173	5.292	6.634	6.137
Eventual work costs	1.282	2.225	1.322	888	918	1.362	1.284
Permanent work costs	17.902	17.902	17.902	17.902	17.902	17.902	17.902
<b>Total costs</b>	<b>156.942</b>	<b>139.070</b>	<b>156.992</b>	<b>142.073</b>	<b>137.598</b>	<b>157.655</b>	<b>147.547</b>
<b>Negative deviation each s.n.</b>	-	-	-	27.753	31.260	39.774	
<b>Expected income</b>	49.675						
<b>Total absolut deviation</b>	99.025						

Source: Model results

From this table we can state that in this farm, traditionally a crop farm, the crops are the activities that most contribute to total profits. Subsidies for these activities represented, in the studied year, an important part of this contribution. On the base situation, subsidies contribution for total profits varies, depending on the type of year, between 44 and 55%. On average, this contribution is 51%. On the technological alternatives situation, subsidies contribution for total profits varies between 41 and 59%, being on average 52%.

We can also state that the difference between the two models lies, basically, in traction costs and permanent work costs.

There is an average gain of 29.845 euros from base situation to technological alternatives situation, due to a reduction on variable costs with traction, and permanent work costs, since the farm will need much less traction hours to perform the needed cultural operations. Nevertheless, base situation as an average gain of 5.385 euros when compared to technological alternatives situation, resulting from less fixed costs with traction and less extra hours needed.

The difference on expected income, between the two situations is mainly due to the difference between these values.

So, there is a fundamental costs difference between base and alternative technologies situation. Although the utilization of the machinery the farmer already has leads to lower fixed costs with traction when the traditional technology is used, more days available to work in the field with alternative technologies and a lower necessity of hours to perform cultural operations with these technologies, lead to less tractors need, less permanent workers and less variable costs with traction.

The results presented demonstrate that, although the expected income is positive in both situations, with technological alternatives is 21.725 € higher; in this situation there are 60% of the years, which mean 3 types of years, in which the economic result is lower then expected, but it is never negative. In the base situation the expected income is lower. In this situation the economic result will also be lower then expected in 60% of the years, but it will never be negative.

These results are influenced by three fundamental factors: the production plans, which are different for the different situations, the available days to work each technology needs and implies and, finally, the farm fixed structure that is a consequence of the first two.

On next tables we present the annual production plans (table 2) and the available days each technology needs and implies (table 3) showing, as we have just stated, that the model considers these aspects and accounts their influence on the economic evaluation of technologies.

**TABLE 2** – Cultural occupation of soils – rotations and seeded areas (ha) – on base and technological alternatives situations

Type of year	1	2	3	4	5	6
<b>Base situation</b>						
<i>Clay soils</i>	<b>Rotations:</b> Sunflower-Durum wheat–Wheat					
	201,5	201,5	201,5	170,1	201,5	201,5
<i>Sandy loam soils</i>	<b>Rotations:</b> Triticale-Oat-Rest-Rest					
	185,0	185,0	185,0	123,0	134,9	185,0
<b>Alternative technologies situation</b>						
<i>Clay soils</i>	<b>Rotations:</b> Sunflower-Durum wheat–Wheat					
	Sunflower-Barley–Wheat					
Direct seeding	57,5	72,8	57,1	51,3	53,2	55,7
Reduced mobilization	144,0	128,6	144,4	112,1	106,4	145,5
<i>Sandy loam soils</i>	<b>Rotations:</b> Triticale-Oat–Fallow-Fallow					
	185,0	185,0	185,0	185,0	183,6	185,0

Source: Model results

In what concerns the available days each technology has and implies, which decisively influence the model result, as we concluded that the difference between the two situations lies, particularly on costs with traction utilization, we can see in table 3 that, for both situations, the critical periods of traction utilization are different, showing the model considers this aspect in traction utilization for both situations.

**Table 3** – Available (A) and used (U) traction hours by critical periods and sub-periods

	A	U	A	U	A	U	A	U	A	U	A	U
Type of year	1		2		3		4		5		6	
Base situation												
Period 1	1029,6	939,9	1056,0	939,9	1135,2	939,9	501,6	735,6	686,4	852,8	1135,2	939,9
Sub-Period 1.3	871,2	737,7	897,6	737,7	924,0	737,7	396,0	594,0	528,0	694,4	924,0	737,7
Alternative Technologies situation												
Reduced mobilization set of traction												
Period 1	343,2	330,7	352,0	249,3	378,4	348,3	167,2	230,7	228,8	249,0	378,4	339,4
Sub-Period 1.3	290,4	290,4	299,2	209,0	308,0	308,0	132,0	198,0	176,0	217,2	308,0	299,2
Sub-Period 2.1	167,2	181,3	369,6	181,3	290,4	181,3	176,0	147,0	105,6	143,1	290,4	181,1
Period 4	457,6	422,4	431,2	338,2	422,4	424,6	448,8	316,8	422,4	291,4	422,4	431,2
Sub-Period 4.2	290,4	422,4	299,2	338,2	308,0	424,6	281,6	316,8	308,0	291,4	308,0	431,2
Direct seeding set of traction (clay soils)												
Sub-Period 1.3	235,1	132,5	237,8	136,4	236,4	122,1	132,2	143,7	152,2	114,3	237,8	75,9
Sub-Period 2.3	127,1	80,5	244,0	101,9	180,4	79,9	138,2	71,9	70,2	74,5	244,0	49,4
Period 4	330,4	305,1	306,6	306,5	298,6	311,0	306,5	282,3	280,9	292,5	306,6	194,1
Sub-Period 4.2	209,7	305,1	212,7	306,5	217,8	311,0	192,3	282,3	204,8	292,5	212,7	194,1
Direct seeding set of traction (sandy loam soils)												
Period 1	125,9	139,4	122,1	139,4	123,8	139,4	108,8	139,4	106,1	139,4	122,1	139,4
Sub-Period 2.3	73,4	66,7	89,0	66,7	85,1	66,7	72,5	66,7	53,1	66,7	89,0	66,7
Period 4	136,4	184,9	124,6	184,9	123,8	184,9	142,1	184,9	141,5	184,9	124,6	184,9
Sub-period 4.1	83,9	82,5	73,8	82,5	69,6	82,5	86,5	82,5	79,6	82,5	73,8	82,5
Sub-Period 4.2	86,5	102,4	86,5	102,4	90,2	102,4	89,3	102,4	103,2	102,4	86,5	102,4

Source: Model results

The most relevant aspects of the cultural occupation of soils presented in table 2 are the fact that alternative soil tillage technologies are always chosen, the non utilization of total clay soils' area, in year type 4, for both situations, the non utilization of these soils also in year type 5 for the alternative technologies situation and the use of total sandy loam soils' area in alternative technologies' situation.

On table 3 we can observe that in base situation the need for traction hours exceeds the availability on period 1 and sub-period 1.3, in states of nature 4 and 5. Since these are winter periods, they have less day light hours and less available days to work in the soil and so the farmer can use only 234 extra hours in period 1 and 198 extra hours in sub-period 1.3. Only in state of nature 4, for both periods, these hours are all used. So these are really the limiting periods and type of year.

For technological alternatives situation the farmer also uses all the extra hours he has during seeding time in state of nature 4. In this type of year, the extra hours are fully used, on reduced mobilization technology, in period 1.3 (66 hours) and on direct seeding in sandy loam soils in period 1 (30.6 hours). For direct seeding in clay soils this resource never limits the cultural occupation of soils on seeding time.

For state of nature 1, traction resource also limits cultural occupation in sub-period 4.2 for reduced mobilization. In the same sub-period this resource is a limiting resource for states of nature 1, 2, 3, 4 and 5 for direct seeding technology on clay soils. For this technology, but in sandy loam soils, traction is the limiting resource in period 4, for the states of nature 2, 3 and 6.

Finally, we shall talk about the fixed structure of the farm, representing long term decisions, and concerning traction sets needed, permanent workers and herd dimension. We can see in table 4 that for the base situation the model chooses 3 traction sets and a threshing harvester, which leads to the need of three permanent workers. For the alternative technologies situation the farmer only needs 2 traction sets, one with a 80 hp tractor for direct seeding and another with a 105 hp tractor for reduced mobilization and a threshing harvester, which leads to the need of only two permanent workers, although in the average there is more seeded area with these technologies.

In what concerns animals, the feeding resources available maintain 416 heads in the base situation, although these animals are divided in two herds with different nutrition exigencies. One of the herds has 329 animals in a more intensive regimen, selling animals with 3 months and 25 Kg life-weight. The other herd has 87 animals in a more extensive feeding regimen, selling animals with 4 months and 20 Kg life-weight. Their feeding base is composed of triticale and oat straw, pasture from fallows and triticale straw ate in the field. This regimen is complemented with granulated feed when necessary. In less productive years, states of nature 4 and 5, animals also eat oat stubbles. In the technological alternatives situation there is only a herd with 403 animals in the more extensive regimen. Feeding is also based on straw, fallows and granulates when needed.

**Table 4** – Traction sets and threshing harvester (n.º), permanent workers (n.º) and herd dimension on the base and alternative technologies situations

<b>Base situation</b>	
Traction sets (120 hp)	3
Threshing harvester	1
Permanent workers	3
Sheep	416
<b>Alternative technologies situation</b>	
Traction set (80 hp)	1
Traction set (105 hp)	1
Threshing harvester	1
Permanent workers	2
Sheep	403

Source: Model results

## 8. Risk evaluation

A larger expected income on the alternative technologies situation also corresponds to a larger total absolute deviation.

Income risk evaluation for the efficient possible production plans, given the probability distribution of the defined states of nature allows the definition of a set of admissible plans for the farm that assure the maximum expected income for each level of standard deviation.

With the objective of determining this set we've parameterized the restriction that corresponds to the sum of total absolute deviations in 25% steps.

The results, as well as optimal activities levels for each solution, are shown in table 5:

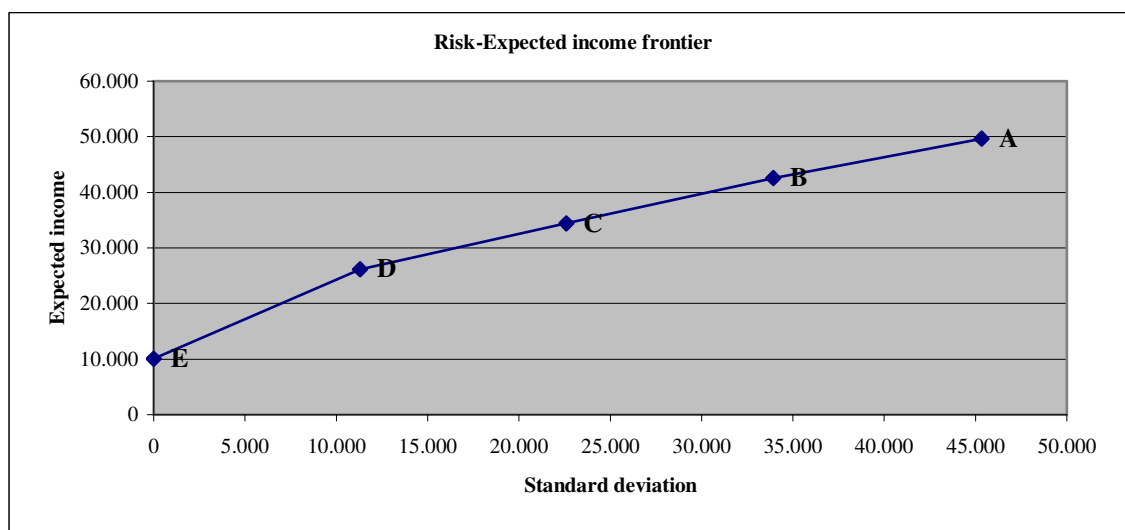
**Table 5** – Model results with parameterization of Total Absolute Deviation value – Total Absolute Deviation (€), Expected income (€) and optimal levels of activities

<b><u>Solutions</u></b>		State of Nature	$\theta$ (A)	$0.75 \theta$ (B)	$0.50 \theta$ (C)	$0.25 \theta$ (D)	0 (E)
Total Abs. Dev.			99.025	74.091	49.396	24.695	0
Expected income			49.625	42.597	34.367	26.137	10.076
ha seeded with alternative technologies	1	1	286	204	271	191	53
	2	2	286	286	214	129	85
	3	3	286	201	239	256	286
	4	4	248	229	229	229	194
	5	5	244	219	219	219	239
	6	6	286	197	197	197	197
	Aver.		270	223	225	206	185
ha seeded with traditional technology	1	1	0	45	0	13	106
	2	2	0	0	50	59	1
	3	3	0	85	48	30	0
	4	4	0	58	58	58	57
	5	5	0	67	67	67	47
	6	6	0	90	90	90	90
	Aver.		0	60	57	57	50
Traction sets	80 Hp	1	1	1	1	1	1
	105 Hp	1	1	1	1	1	1
	120 Hp		1	1	1	1	1
Sheep			403	405	405	405	405

Source: Model results

The frontier that represents the efficient set of production plans, on which the risk is the minimum for each level of expected income, is shown on graphic 1. The letters correspond to those on table 5. On the graphic the income is measured by expected result and risk by its standard deviation, being the variance estimated from the total absolute deviation.

Unit.: Euros



Source: Model results

**Graphic 1** – Risk-Expected income frontier

From the farmers point of view, the application of Compromise Programming to the studied economic model, assuming the farmer gives the same weight to both its objectives (obtaining the higher expected income and have the lower variation of this income) has the following results:

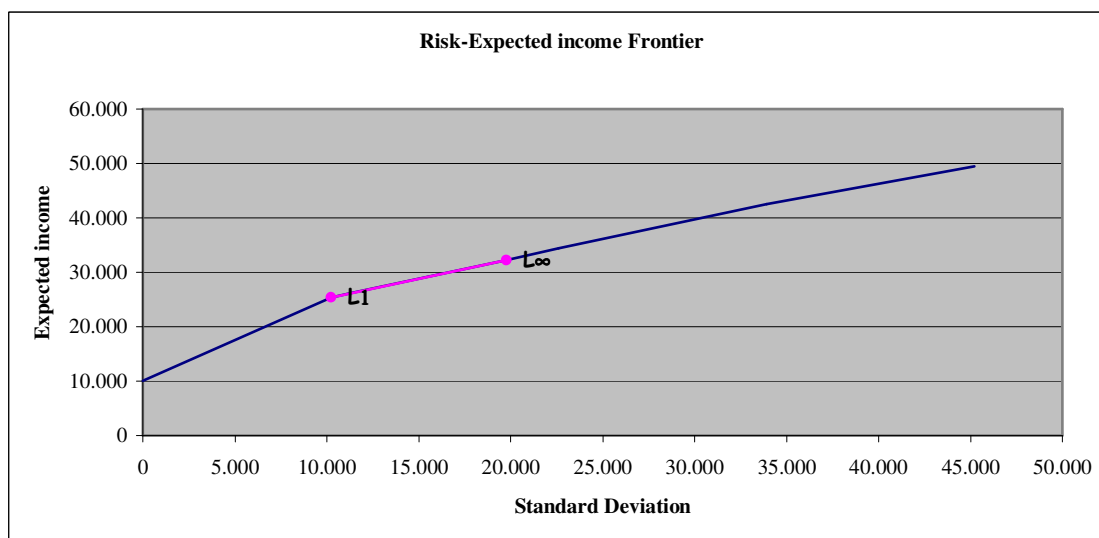
**Table 6** – Studied Model results, for extreme points  $L_1$  e  $L_\infty$  - Total Absolute Deviation and Expected Income (euros)

Extreme points	Objective function	
	Total Absolute Deviation	Expected Income
$L_1$	22.356	25.354
$L_\infty$	43.186	32.297

Source: Model Results

Graphically, these results correspond to the following (graphic 2):

Unit. Euros



Source: Model Results



**Graphic 2 – Risk-Expected income frontier**

According to these results we can state that a farmer who gives the same weights to both its objectives will privilege the utilization of alternative soil tillage technologies but will also use traditional technology. On the average the farmer will mobilize 211 ha of his farm with alternative technologies and only 57 ha with traditional technology.

**9. Conclusions**

This work proposes a methodology to the soil tillage technology economic evaluation in a risky environment.

The model considers to main aspects:

- The greater income variability resulting from the use of alternative soil tillage technologies loses importance when compared to the enormous cost difference among the two studied situations – alternative and traditional soil tillage technologies.
- The balance between income risk and the investment - when the farmer is using a set of traction for traditional technology and considers income risk, it is still interesting, from an economic point of view, to continue using traditional technology, which means the farmer's decision will take this into account. This way, we can think that farmers will let their equipments be fully paid off and only when it will be necessary to substitute the equipments they will adopt alternative tillage technologies. This result also allows the extrapolation that in a difficult economical situation, that imposes the farmers some investment restrictions, the substitution and adoption of alternative technologies will be even more gradual

We prove the mathematical programming model solution accounts for the probability of occurrence of each state of nature and give an investment solution considering the best production plan for each state of nature.

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